Electrical Engineering Research Laboratory
The University of Texas
Austin, Texas

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UNPUBLISHED PRELIMINARY DATA

AN INVESTIGATION OF 35 GC, 70 GC AND 94 GC CYTHEREAN RADIATION

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Technical Report No. 2
Grant NsG-432

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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ABSTRACT

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This report describes the observing techniques and the results of measurements conducted between 10 April and 22 August 1964 of emission from Venus at 35 Gc, 70 Gc and 94 Gc. A 16-foot diameter antenna system in conjunction with conventional 10 Mc IF bandwidth radiometers was used for the measurements.

The average brightness temperatures during the period of the observations were 375°K, 330°K and 300°K at the frequencies of 35 Gc, 70 Gc and 94 Gc, respectively. No large dependency of the brightness temperatures on the Cytherean phase at these millimeter wavelengths was noted. Such brightness temperature-phase dependencies that were observed, in conjunction with the correlation of the millimeter wavelength brightness temperatures with the Fraunhofer Institut sunspot indices, and the good spectral description by an ionospheric model of both the millimeter wavelength brightness temperatures and the centimeter wavelength brightness temperatures of other observers suggests that an ionospheric model is singularly the most suitable for describing the Cytherean radiation.

Author

I. INTRODUCTION

Interest in Cytherean radiating characteristics, defined by measurements at many different wavelengths on many different occasions, has been heightened by the prospect of physical exploration of the planet by the National Aeronautics and Space Administration and many and varied models have been proposed to explain the level of radiation.[1, 2, 3, 4, 5] To resolve some of the degrees of modeling freedom allowed by the observed spectrum an extension of measured values of brightness temperatures into the domain of the millimeter wavelengths is required. The millimeter wavelength observations must be conducted with the resolution of both line and continuum spectra in order to obtain information on the physical nature of the source that is available through the radiation and absorption of gaseous line spectra.

The measurements described in this paper were conducted at the frequencies of 35 Gc, 70 Gc and 94 Gc with a 16-foot diameter antenna.[6] The 35 Gc measurements were made to associate the relative brightness temperature of the three frequencies to the brightness temperature of a frequency at which a number of measurements have been reported. While the three frequencies are too widely spaced to yield significant line spectra and even the bandwidth of the radiometer at each frequency is excessively wide for low pressure gas line resolution, the absorption minima of the earth's atmosphere at 35 Gc and 94 Gc make these frequencies attractive for earth-based observations. By including 70 Gc, a frequency at which components are conveniently available and a frequency as far removed from the other two as the oxygen absorption in the earth's atmosphere will allow normal earth-based observations to be made, a crudely defined spectrum was hoped for.

II. INSTRUMENTATION AND OBSERVING TECHNIQUES

Conventionally designed Dicke-type ac radiometers with 30 cps mechanical modulators were used in conjunction with the 16-foot millimeter wavelength antenna system for the measurements. The rms uncertainties of the radiometers were 1°C, 5°C and 7°C for integrating periods of one second at the frequencies of 35 Gc, 70 Gc and 94 Gc, respectively. The radio frequency components and the 10 megacycle bandwidth IF preamplifiers were incorporated at each frequency with the antenna feed horns and supported singularly by the antenna spars at the prime focusing of the 16-foot parabola. The feed horns accepted 10 db periphery tapered energy from the parabola with resulting antenna gains of 62.5 db, 68.5 db and 70.9 db, at the frequencies of 35 Gc, 70 Gc and 94 Gc, respectively. The remainder of the radiometers, the IF amplifier, the narrow bandwidth amplifier-synchronous detector and the assorted power supplies, were commonly used at three frequencies.

Analog recordings of the millimeter telescope output were made during right ascension scans of the antenna beam across Venus. At each frequency the polar axis drive rate was adjusted to scan in the period of 10 radiometer time constants an angle relative to Venus equal to the antenna half power beamwidths. Scans were repeated over an angle of ± 3 antenna beamwidths as frequently as possible when Venus was within ± 2 hours of the meridian, and markers were applied to the data sample recordings when optical telescopes collimated with the millimeter telescope beam pointed at Venus.

The optical telescopes were collimated with the antenna beam by pointing the millimeter telescope for equal singlas at the north-south point of the moon and aligning the cross-hair radicals of the telescopes with the limbs of the moon. Collimation was performed at declination angles as near as possible to that of Venus to minimize optical-millimeter wavelength refraction differences and mechanical antenna beam-optical beam differences.

A single value of the atmospheric attenuation for an average value of altitude angle was used to evaluate the millimeter wavelength extinction each day. The attenuation values were derived from radiosonde data of the total precipitable water in the atmosphere. Waveguide terminations immersed in boiling and tap water temperatures, electrically heated black bodies and gas noise tubes were used to calibrate the radiometer. The average full scale pen and paper antenna temperature recordings were 6°C, 30°C and 40°C at the frequencies of 35 Gc, 70 Gc and 94 Gc, respectively.

III. RESULTS

Observations were attempted each day between April 10 and August 22, with the exception of those days omitted when Venus was within ±1 hour of the sun. Data were excluded when clouds prevented optical confirmation of the antenna pointing, when, during the approximately 3 to 6 minutes of a data sample scan, the variability of the emission and absorption of the atmosphere drastically disturbed the low frequency components of the signal level or when the positions of the antenna side lobes relative to the sun drastically disturbed the low frequency components of the signal level. Examples of the results obtained by averaging at 1/12 antenna beam width intervals data samples from single days or groups of days are shown in figure 1. The solid curves are radiometer time constant transformed antenna pattern responses to point sources best-fit to the measured values.

The brightness temperatures of Venus were evaluated from the antenna temperatures with the following expressions:

$$T_s = T_a \left[\frac{41,253}{(Ag)(K\Omega_s)(\Omega_s)^2} \right] e^{0.23\Gamma}$$

T_s = source brightness temperature (°K)

T_a = antenna temperature (°K)

A_g = antenna gain (maximum relative to isotropic source)

$K\Omega_s$ = antenna gain correction for source size

Ω_s = angle subtending source (deg.)

Γ = attenuation through the Earth's atmosphere (decibels)

$$\Gamma = 0.10 + 0.11\,(\rho_\omega)\sec\phi \qquad \text{(at 35 Gc)}$$

$$\Gamma = 1.70 + 0.16\,(\rho_\omega)\sec\phi \qquad \text{(at 70 Gc)}$$

$$\Gamma = 0.65 + 0.33\,(\rho_\omega)\sec\phi \qquad \text{(at 94 Gc)}$$

ρ_ω = precipitable atmospheric water vapor (grams/cm^2)

ϕ = zenith distance (degrees).

The uncertainties of the brightness temperatures are represented by the following expressions:

$$\Delta T_s = T_s \cdot A_p \pm \sqrt{(Ag)^2 + (T_a)^2 + (T_c)^2 + (e^{0.23\Gamma})^2}$$

ΔT_s = source temperature uncertainty

A_p = antenna pointing uncertainty
(5% at 94 Gc, 3% at 70 Gc and 0% at 35 Gc)

A_g = antenna gain uncertainty
(12% at 94 Gc, 8% at 70 Gc and 5% at 35 Gc)

T_a = antenna temperature uncertainty
(variable with number of data samples averaged)

T_c = temperature calibration uncertainty
(5% at 94 Gc, 5% at 70 Gc and 5% at 35 Gc)

$e^{0.23\Gamma}$ = absorption uncertainty
(5% at 94 Gc, 5% at 70 Gc and 5% at 35 Gc)

Graphs of the 35 Gc, 70 Gc and 94 Gc antenna temperatures as a function of time, graphically displaying the magnitude of the correction for atmospheric extinction, are shown in figure 2. The 35 Gc, 70 Gc and 94 Gc brightness temperatures of Venus as functions of time, Cytherean phase (included angle between the Earth, Venus and the Sun) and fractional Cytherean disk illuminated are shown in figure 3. The nominal brightness temperature uncertainties are +14% - 14% at 35 Gc, +17% - 11% at 70 Gc and +19% - 9% at 94 Gc.

IV. DISCUSSION

Temperatures of approximately 250°K and 350°K are prescribed for rapidly and synchronously rotating bodies, respectively, with an albedo of 0.7 at the position of Venus relative to the Sun. The spectral brightness temperature of Venus as defined by some of the measured values is shown in figure 4. The 35 Gc, 70 Gc and 94 Gc values are average temperatures measured between April 10 and August 22, 1964.

Planetary emission (T_e) can be represented by the expression

$$T_e = \sum_{i=1}^{n} \epsilon T_i \quad 1 - e^{-\alpha_i \Delta z_i \sec\theta} \quad e^{-\sum_{i=1} \alpha_{i-1} \Delta z_{i-1} \sec\theta}$$

T_e = emission temperature

T_i and α_i = temperature and attenuation of the element of depth Δz inward through the planetary mantle (atmosphere) and core (surface)

ϵ = emissivity of planetary element

θ = angle of the observation relative to the emitting element zenith.

A summation of T_e for all values of θ over the planetary disk yields the brightness temperature. The zenith emission from an isothermal mantle and an isothermal core is:

$$T_e = T_m(1 - e^{-\tau}) + T_c e^{-\tau}$$

T_m = mantle temperature

T_c = core temperature

$\tau = \int \alpha dz$

The Cytherean spectrum can be described either by radiation from a hot core and a cold mantle increasingly opaque from 10 Gc to 100 Gc (thermal model)[1, 3, 4, 7] or by radiation from a hot mantle decreasingly opaque from 10 Gc to 100 Gc and a cold core (nonthermal model)[2, 5, 8].

To obtain a hot surface temperature, "greenhouse" heating by a mantle of low optical wavelength opacity and high infrared wavelength opacity (caused by a small density of a strongly absorbent gas, such as H_2O, or a large density of a weakly absorbent gas, such as CO_2) or friction heating at the surface by wind-driven dust aerosols (agitated by solar radiation absorbed at high altitudes by dust clouds) have been proposed.

To obtain a hot mantle temperature, free-free radiation from a high density ionosphere (caused by solar ionization of the mantle in the absence of magnetic shielding) or radiation from charging and discharging of the large aerosol particles (resulting from the charge accumulation of precipitating particles) has been proposed.

Representative examples of the 10 Gc to 100 Gc spectrum of each model are displayed with the measured brightness temperature values in figure 5. Within the uncertainty limits of the absolute brightness temperatures all models describe the observed spectrum.

Brightness temperatures at 4 Gc and 9.53 Gc as functions of Cytherean phase (i) are described by the following expressions[9,10]:

(3 Gc) $622°K + 41 \cos (i - 21)°K$

(9.53 Gc) $621°K + 73 \cos (i - 11.7)°K$

Expressions of the Cytherean phase dependencies of the 35 Gc, 70 Gc amd 94 Gc brightness temperature are unobtainable from the data due to the apparently small dependency factors relative to the uncertainties and sparseness of brightness values at each of the frequencies. The Rank Difference correlation coefficients of the Fraunhofer Institut sunspot indices, adjusted for the position of Venus relative to the Earth-based observations, with the millimeter brightness temperatures are 0.80 at 35 Gc, 0.75 at 70 Gc and 0.35 at 94 Gc. The quality of the correlation of the millimeter wavelength brightness temperature perturbations with the solar indices enhances the possibility that the Cytherean radiation is, in part, ionospheric.

Scaled millimeter wavelength phase-brightness temperatures from an average of the 3 Gc and 9.53 Gc phase-temperature characteristics based on an ionospheric model having a hot mantle and cold core of 620°K and 280°K, respectively, (electron temperature $\sim 620°K$, electron density $\sim 10^9 \text{ cm}^{-3}$ and integrated squared electron density through ionosphere is 10^{26} cm^{-5}) are as follows:

(35 Gc) $375°K + 17 \cos (i - x)°K$

(70 Gc) $330°K + 9 \cos (i - x)°K$

(94 Gc) $300°K + 4 \cos (i - x)°K$

If any phase characteristics of the millimeter data of figure 3 is to be recognized there is an apparent phase advance of the millimeter wavelength minimum brightness temperature relative to that of the centimeter wavelengths to a time preceding inferior conjunction. Such an interpretation implies, for an ionospheric model, that the predominating core radiation at the millimeter wavelengths originates from a slightly retrograde rotating planet. The spectral contributions from the mantle and the core of the ionospheric model are shown in figure 6.

There are acknowledged objections to the ionospheric model based on the intensity and character of the radar returns from Venus.[8] It is also to be recognized that each model in itself probably oversimplifies a complex environment and that a combination of the elements of the model are required to describe the radiation in detail, certainly the inclusion of water vapor would improve the "spectral fit" around 20 Gc and provide the characteristic of increasing the rate of extinction between 35 Gc and 180 Gc as exhibited by the median 35 Gc, 70 Gc and 94 Gc values.

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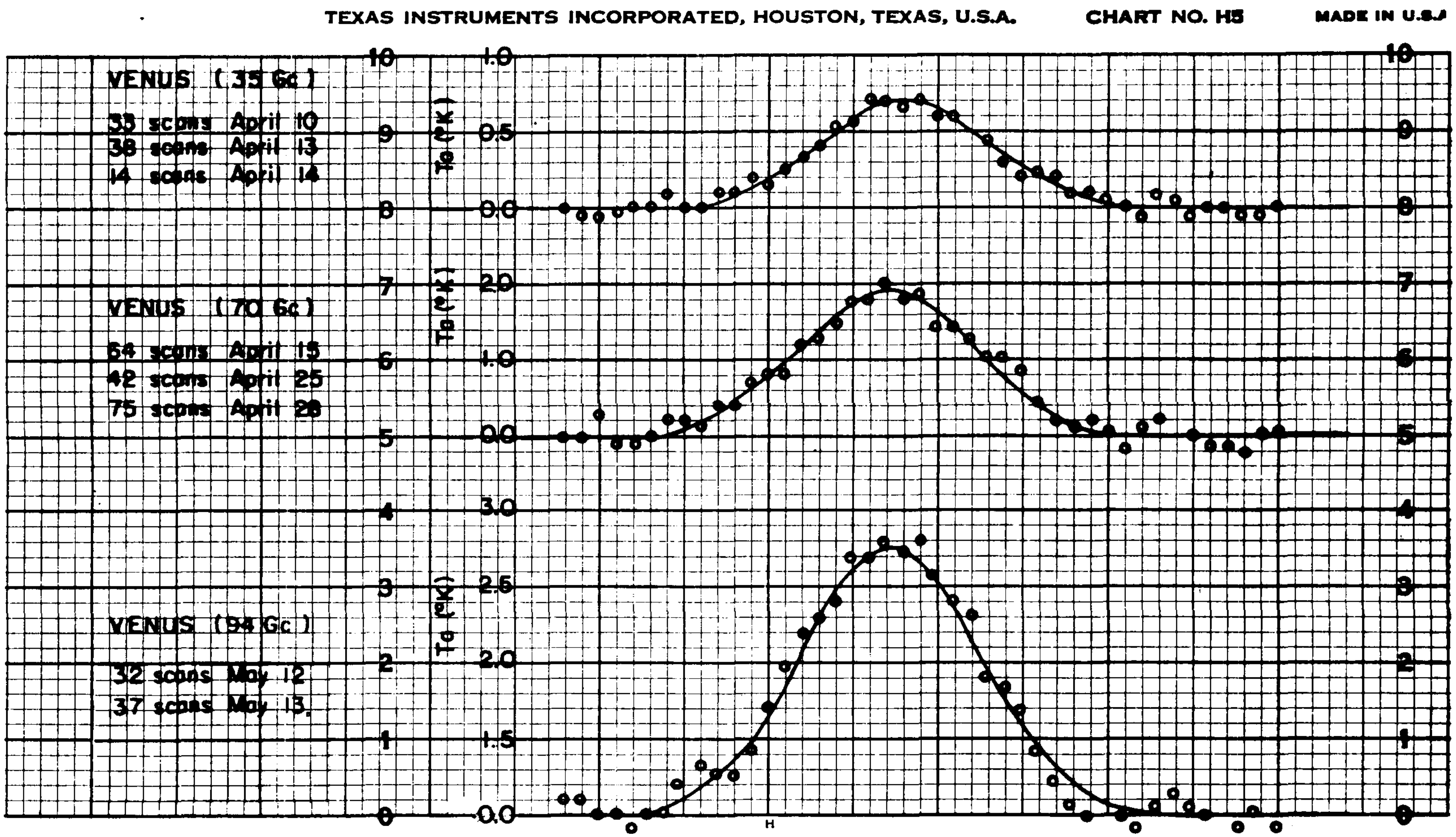
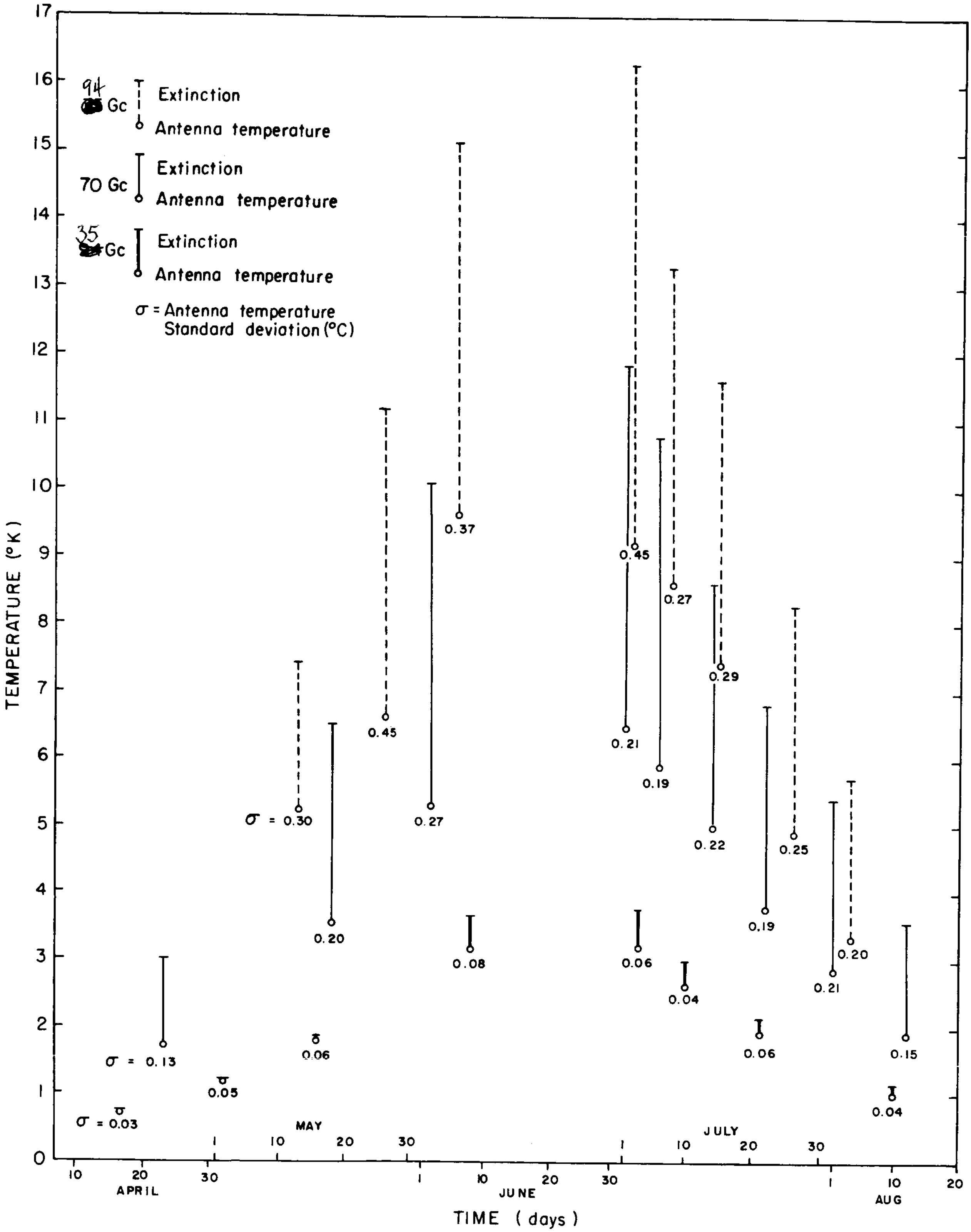


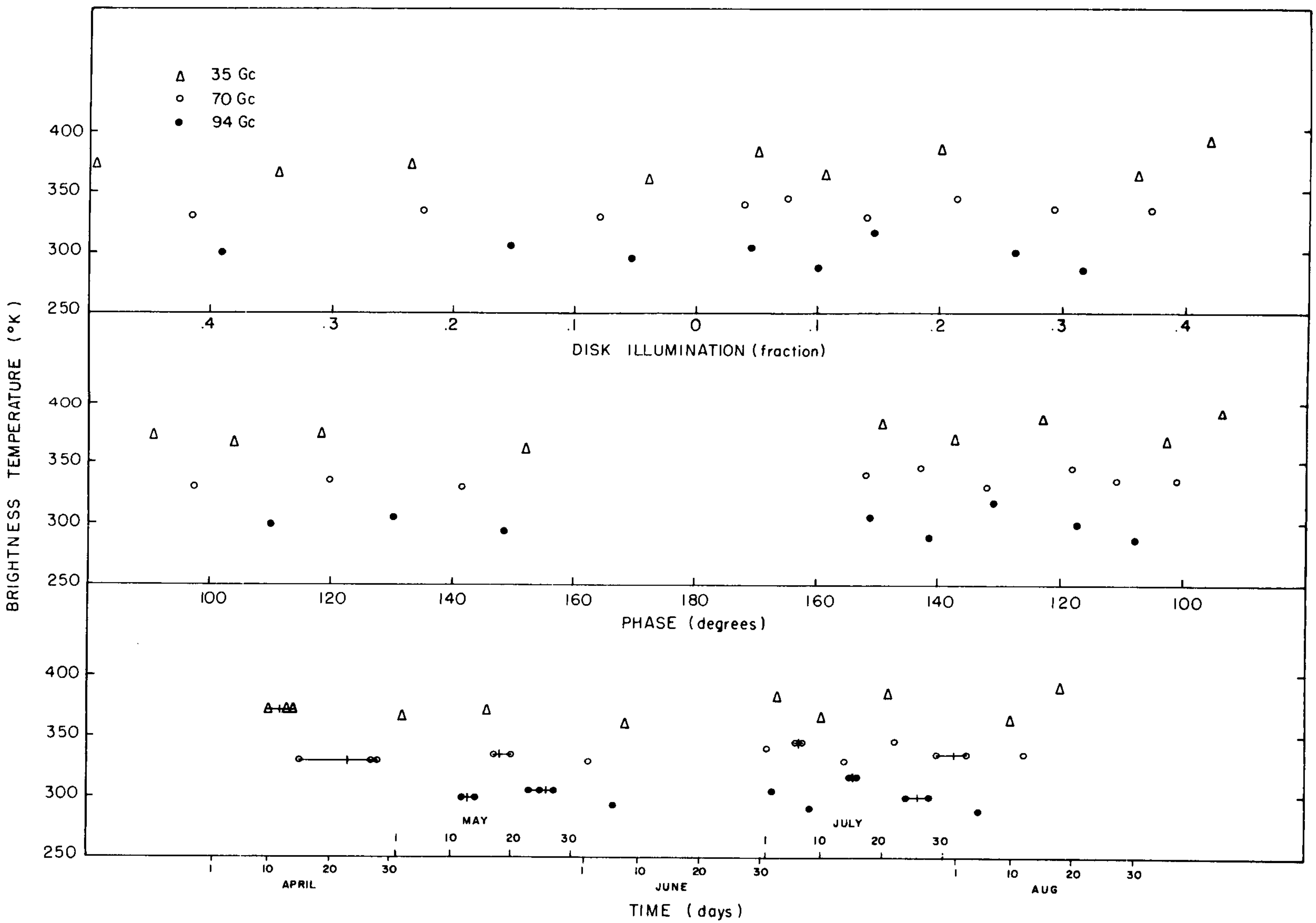
EXAMPLES OF ANTENNA TEMPERATURES OBTAINED FROM AVERAGES OF DATA SAMPLES NEAR EASTERN ELONGATION

FIG. 1.



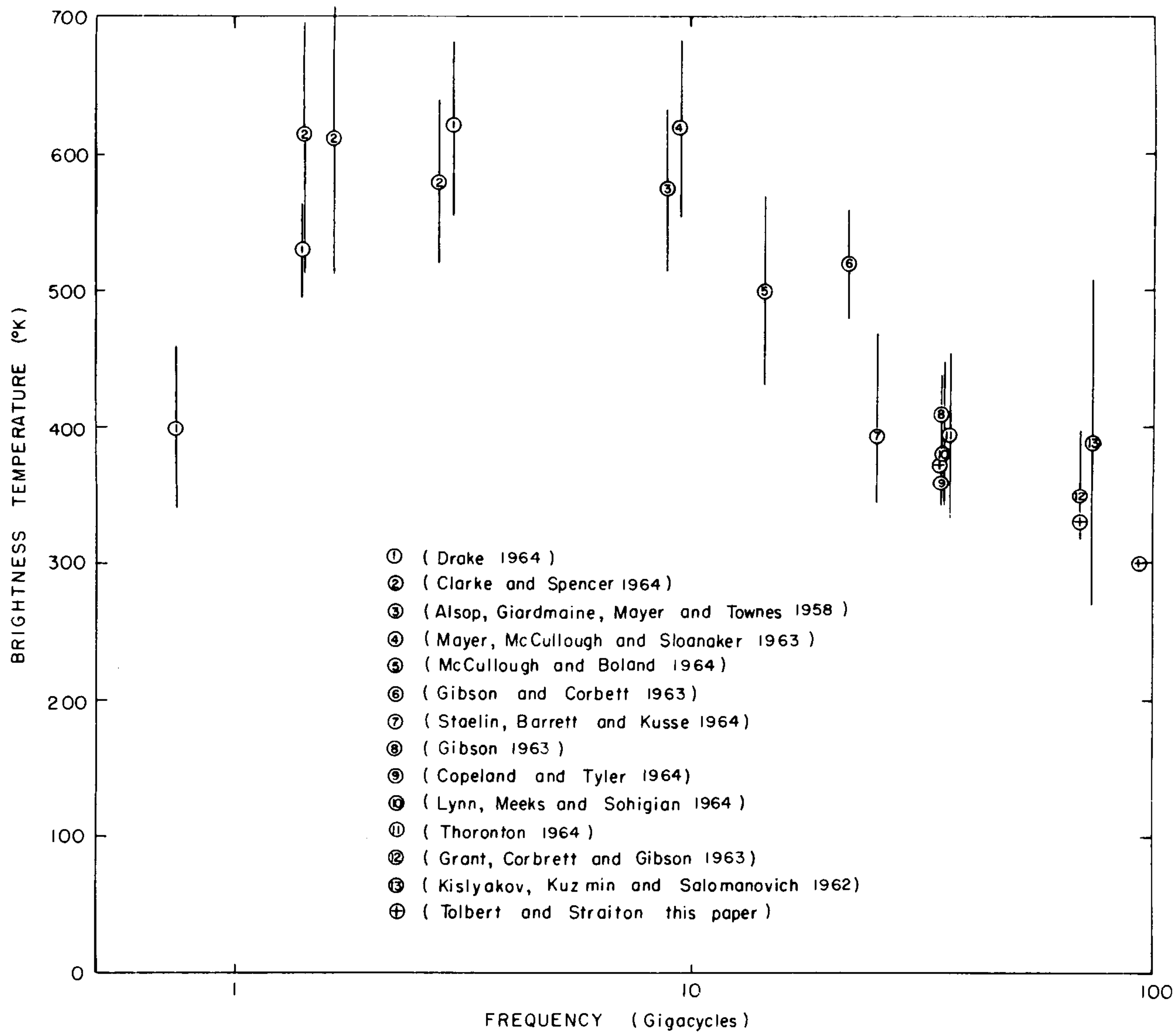
THE 35 Gc, 70 Gc AND 94 Gc ANTENNA TEMPERATURES AND ATMOSPHERIC EXTINCTION CORRECTIONS

FIG. 2.



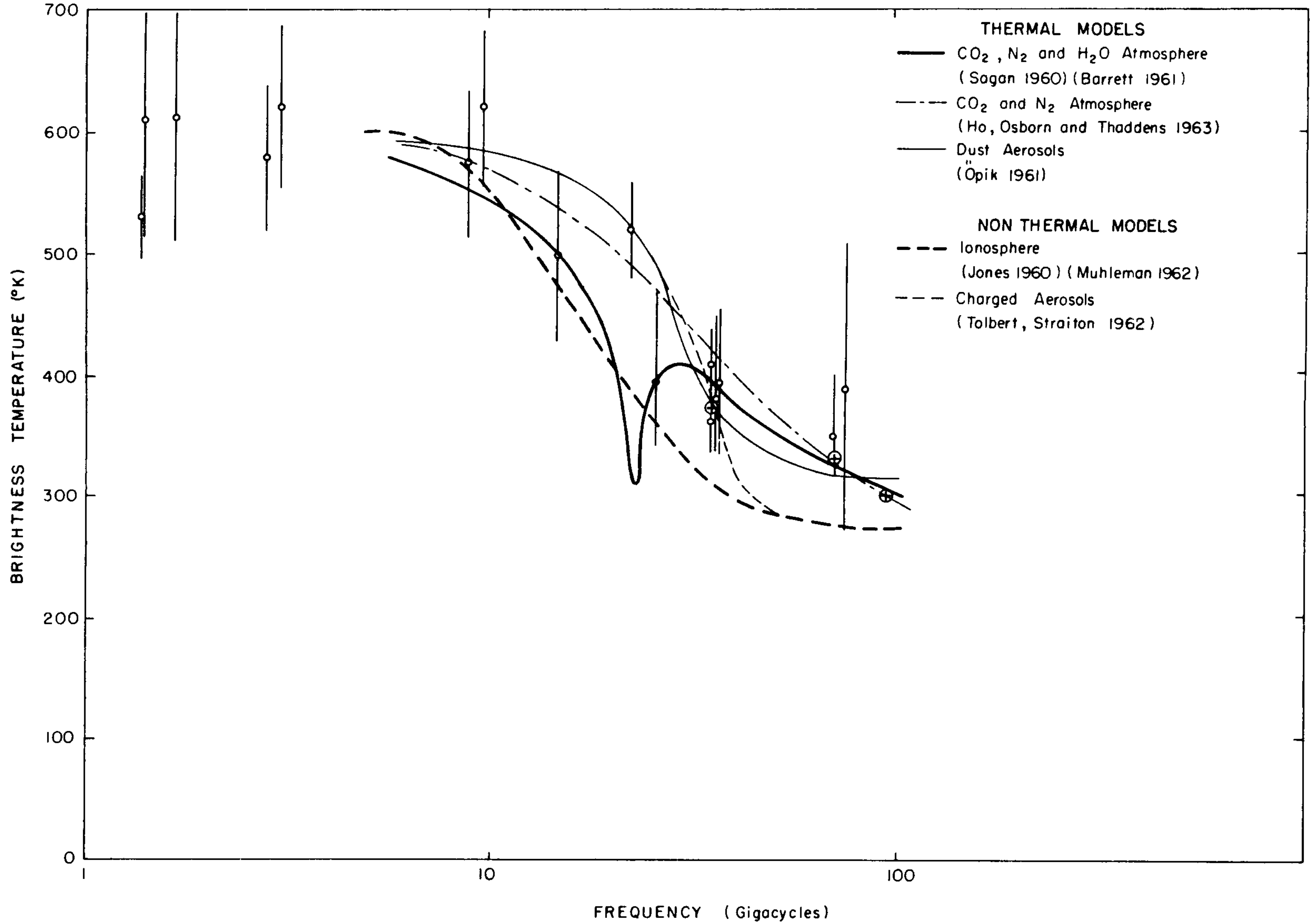
CYTHEREAN 35 Gc, 70 Gc AND 94 Gc BRIGHTNESS TEMPERATURES
AS FUNCTIONS OF TIME, PHASE AND DISK ILLUMINATION

FIG. 3



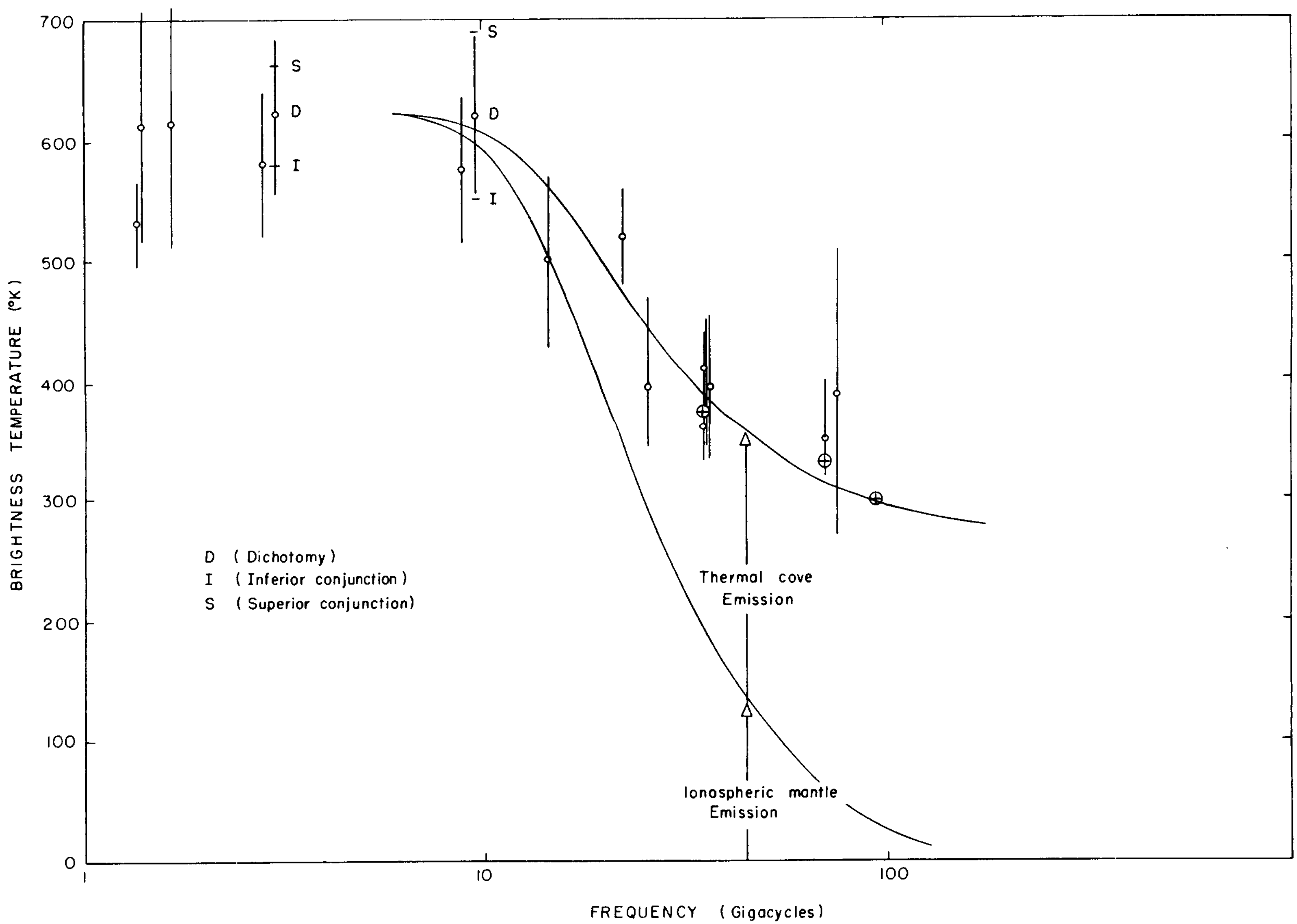
DATA REPRESENTATIVE OF OBSERVATIONS DEFINING
THE SPECTRAL BRIGHTNESS TEMPERATURE OF VENUS

FIG. 4.



EXAMPLES OF SPECTRA OF PROPOSED MODELS
DESCRIBING CYTHEREAN RADIATING MECHANISM

FIG. 5.



CALCULATED IONOSPHERIC CYTHEREAN SPECTRUM
LEAST DESCRIBING OBSERVATIONS

FIG. 6.